Greater Vertebral Bone Mineral Mass in Exercising Young Men

JON E. BLOCK, PhD; HARRY K. GENANT, MD, *and* DENNIS BLACK, MA, *San Francisco*

Peak bone mass at skeletal maturity may be an important factor in the relative quantity of skeletal mass in old age. We have studied bone mineral in 46 young men, 28 of whom engage in regular and vigorous exercise programs. Spinal trabecular bone mineral density and spinal integral bone mineral content are significantly greater in the exercise group as compared with the 18 control subjects. Of the exercise group, subjects participating in both aerobic and weight-bearing regimens have the greatest spinal bone mineral mass, followed by those engaging in strictly weight-bearing exercise and those in a primarily aerobic program. An analysis of variance across all subject groups, including the control group, shows a significant difference in spinal trabecular bone density based on the type of physical activity.

(Block JE, Genant HK, Black D: Greater vertebral bone mineral mass in exercising young men. West J Med 1986 Jul; 145:39-42)

The continuous medical and public health efforts to reduce the occurrence of infectious and other fatal diseases have acted, in part, to reshape the national demographic structure.[1] As a result of an overall increase in the number of elderly persons, chronic diseases have emerged as the primary cause of disability and death.[2] Among the more prevalent of these conditions is osteoporosis as it primarily strikes older age groups.

Most research over the past two decades on osteoporosis and other age-related skeletal changes has focused on the histomorphometry, pathogenesis and physiology of this condition and, most recently, on the development of therapeutic interventions.[3-6] An increase, however, in the number of osteoporotic fractures commensurate with the expected demographic trend demands further attention to preventive strategies to combat this syndrome.

One possible strategy is to increase "peak" bone mass and strength in the young population. Types of exercise programs, as well as intensity and duration of exercise, have not been well studied or described in research dealing with skeletal health. Nevertheless, research to date has shown weight-bearing exercise to have positive effects on increasing bone mass regionally.[7-9] Aerobic forms of exercise such as running and swimming are likewise thought to have positive effects.[10,11] A recent study in a middle-aged population has shown the amount of bone mineral to be as much as 40% greater in the trabecular bone of the spine when comparing long-distance runners with controls.[12] The assessment of the amount of bone mineral at this site is of particular importance because of its primary susceptibility to atraumatic fracture and its presumed responsiveness to external and metabolic stresses.[13,14]

We have measured the amount of the spinal bone mineral in regularly exercising young men using quantitative computed tomography (CT). Most of these men have been habituated to many years of strenuous activity. We compared our results with bone mass calculations from physically inactive men.

Methods

Subjects

We recruited for exercise and control subjects by using several techniques: placing notices in athletic organization newsletters, personally visiting health clubs and dispensing brochures among medical students and hospital employees. All responders were invited to participate in an initial clinic visit on a volunteer basis in which they completed a research questionnaire and at which their spinal bone material was quantitatively assessed using CT. The research questionnaire, divided into four sections, assessed physical activity levels, medical history, diet and various behavioral patterns. Inclusion in the study was based on age (20 to 31 years) and either a history of vigorous physical activity or relative sedentariness. Subjects whose level of exercise did not fall into either physical activity extreme were excluded. Blacks were excluded from the study because of their apparent resistance to osteopo-

From the Department of Radiology, University of California, San Francisco (Dr Block and Dr Genant), and the Clinical Epidemiology Program, San Francisco General Hospital Medical Center (Mr Black).

This study was supported by grants from the American Foundation for Aging Research and NAS9-15887.

Reprint requests to Jon E. Block, PhD, Department of Radiology, University of California, San Francisco, San Francisco, CA 94143.

rotic fractures. Other exclusion criteria were a history of steroid usage, thyroid disorders, diabetes mellitus and other metabolic conditions known to affect skeletal status.

The exercise group consisted of 28 men who had participated in strenuous exercise programs for at least two years. The exercise group was further categorized as follows: vigorous aerobic exercise was defined as at least 40 miles per week of running or six hours per week of aerobic exercise classes. Vigorous weight-bearing exercise was defined as at least six hours per week of rigorous weight lifting either with "free" weights or resistant weight training. A combination regimen was defined as either six hours per week of aerobic or "circuit" weight training, or six hours total per week of weight-bearing exercise coupled with running, swimming or other forms of aerobic exercise.

The control group, consisting of 18 men, was selected based on the criteria of the absence of participation in organized team sports, varsity athletics, intramurals and active membership in a health or fitness club. No control subject was currently involved in a regular program of physical fitness.

Bone Mass Measurements

The techniques for vertebral mineral measurement using computed tomography have been described elsewhere.[15] Briefly, a localization system (computed radiograph) is used to define the region to be scanned, the first and second lumbar vertebrae. A 10-mm thick scan is taken at the midvertebral body of L-1 oriented parallel to the end-plates to determine trabecular bone mineral density. This scan is done at 80 kilovolts (peak) (kV[p])—that is, single-energy scanning. Additionally, 18 contiguous 5-mm thick scans are obtained at 80 kV(p) scanning from the top of L-1 to the bottom of L-2 to determine the measure of total integral bone mineral content. For trabecular density, the mean CT number, a measure of x-ray attenuation, is determined for a 3- to 4-ml volume within the vertebral body and referenced to a mineral-equivalent calibration standard scanned with the subject. Data are analyzed on a specially programmed off-line computer. Subject time for the scan is ten minutes and radiation exposure is about 150 mrem to a 10-cm portion of the torso, with less than 10 mrem gonadal dose. Reproducibility for the technique is 1.6% in normal, healthy subjects.[16] Peripheral measurements of cortical bone were not done on any participants in this study.

Two types of analyses were carried out: the standard trabecular bone density and total integral bone mineral content. The former reflects the density (mg per cc) of trabecular bone in the midportion of the vertebral body, whereas total integral bone reflects the mass (grams) of compact and trabecular bone contained in the entire vertebrae of L-1 and L-2. Total integral bone mineral content was also divided by vertebral size and expressed as a density measure (mg per cc) to account for intergroup and intragroup variation in vertebral size. Total integral bone mineral content was not determined in every subject due to technical problems or alterations in scanning protocols.

Data Analysis

Data were entered and analyzed using Statistical Analysis System (SAS) software on the IBM 4341 mainframe at the University of California, San Francisco, Medical Center. Statistical significance of mean differences was assessed using a two-sample *t* test for two group comparisons and a one-way analysis of variance for three or more group comparisons.

Results

Height, weight and age for all participants are given in Table 1. Because an effort was made to create a uniform age distribution in the two study groups, there was only a small difference in mean age (27.6 years versus 25.9 years) and any differences in bone mass among the groups would not be expected to reflect age-related changes in bone. Mean body weight was 2.3 kg greater in the exercise group; previous studies, however, have not shown an association between body weight and trabecular bone density as determined by quantitative CT.[15,17] The exercise study group, based on the type of exercise program, was further divided as follows: ten men engaged in an aerobic and "impact-loading" regimen (such as running), nine men did weight-bearing exercise (weight lifting) exclusively and nine men engaged in a program that combined weight bearing and aerobic exercises (circuit weight training).

A comparison of measurements of trabecular bone density, total integral bone mineral content, total integral bone density and vertebral size for both study groups is given in Table 2. Spinal trabecular mineral density was 14% greater in the exercise group compared with the control group (184.02 mg per cc versus 161.34 mg per cc, $P = .0001$). The measure of total integral bone mineral content for L-1 and L-2 vertebrae for 26 of the physically active men was 11% greater than for 11 of the controls. Active men had a value of 41.6 grams of total bone and sedentary controls had 37.5 grams ($P = .04$). The results for total integral bone density indicated that integral bone density was slightly greater in the exercise groups as compared with control men (258.3 versus 253.9 mg per cc) but this difference was not statistically significant ($P = .67$). Vertebral size was 10% greater in the exercise group (164.1 cc versus 148.6 cc), but this difference did not reach statistical significance ($P = .18$).

Mean trabecular bone density by exercise type is shown in Figure 1. Persons engaged in a program that used both weight-bearing and aerobic forms of exercise had a mean value of trabecular bone density of 197.3 mg per cc, whereas those engaging in purely weight-bearing regimens had a mean value of 183.1 mg per cc and the aerobic exercise group had a mean value of 172.9 mg per cc. Men in the control group were lowest with a mean value for trabecular bone density of 161.3 mg per cc.

An analysis of variance was used to test for a significant difference across all four groups—that is, control, aerobic, weight bearing and aerobic plus weight bearing. There was a significant difference between groups for trabecular bone density ($P = .0001$). Differences in total integral bone mineral (grams) and total integral bone density (mg per cc), however, were not significant.

Preliminary analysis of the study questionnaire indicated that no identifiable dietary differences existed between groups. Intake of dairy products was comparable among the groups and was estimated at about 800 mg per day using standard references for calcium-containing foods. Three subjects in the exercise study group, however, did consume greater amounts of calcium-containing foods (about 1,800 mg per day). Various dietary or nutritional supplements, such as vitamins, were used with greater frequency in the exercise group, with 21 (75%) subjects consuming at least one multivitamin or 1,000 mg vitamin C per day, whereas five sedentary men (28%) used nutritional supplements on a regular basis. No participants supplemented their diets with either vitamin D or calcium compounds. No participants in the study, either exercisers or controls, currently smoked cigarettes or had a history of heavy drug or alcohol usage.

Discussion

Vertebral trabecular bone mineral density is 14% greater in the exercise study group than in the control population. The difference between the two study groups supports previous research showing greater regional bone mass at appendicular sites for exercisers versus nonexercisers.[7,10,11] Integral bone mineral content in the spine is also greater in the exercise group; the percentage difference between groups, however, is 11%, just reaching statistical significance. Research has shown that the trabecular bone envelope may be a more sensitive area for measurement due to a turnover rate that is eight times greater than for cortical bone.[4,15] The measure of integral bone by CT, moreover, is subject to a greater variability in the technique than the trabecular measurement and, therefore, may not sensitively indicate subtle physiologic differences between study populations. A relatively smaller difference (2%) in integral density occurring between groups indicates that the larger vertebral size in the exercise group directly affects the measure of total integral bone mineral. Consequently, our data would suggest a more thorough examination of the effects of various types of exercise on trabecular bone density and vertebral size to differentiate the independent effects on various bone compartments over time.

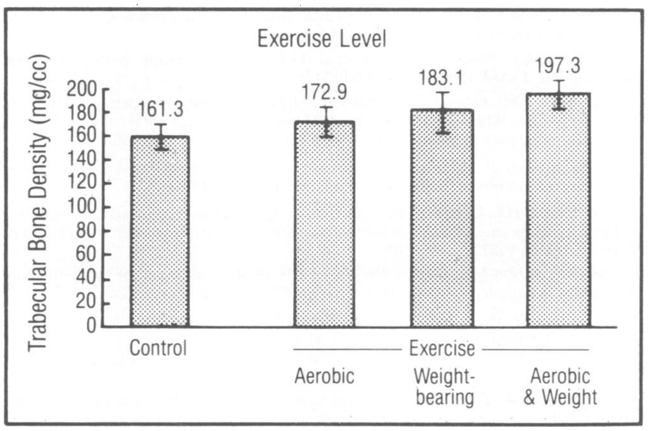

Figure 1.—This histogram, showing mean trabecular bone density by exercise level, shows progressively greater vertebral trabecular bone mineral through each exercise type.

Diet did not appear to be substantially different between groups, especially in regard to dairy products. The use of vitamins was a more common finding in the exercise group. Research to date, however, has not adequately assessed the effects of these nutritional supplements on skeletal mass.[18-20]

Little is known about the effects of different exercise regimens on skeletal mass. Our results show a differential response based on exercise type: the weight-bearing plus aerobic exercise group showed the greatest bone mineral mass and the purely aerobic exercise group showed the smallest increment in bone mineral mass. Interestingly, a general trend is apparent in our data that would support the hypothesis that lack of exercise may have adverse effects on the skeleton,[21] whereas a more comprehensive regimen combining weight-bearing and aerobic forms of exercise appears to be the most beneficial, with other forms of exercise falling in between (see Figure 1). An effort was made to compare groups according to similar amount of time spent exercising each week, and exercise duration was not found to be different between groups. It is difficult to determine from self-report data, however, if persons partaking in different regimens for a similar duration are doing so at comparable levels of intensity.

A bank of clinical normative data describing a general cross section of the normal population has been previously reported from our center.[22] Based on the limited data for men

TABLE 1.—*General Characteristics of Study Groups**

Study Group		*Age, yr*	*Height, m*	*Weight, kg*	*Exercise Type*
Exercise	(N = 28)	25.9 ± 3.5	1.79 ± 0.03	73.1 ± 2.7	. . .
A	(N = 10)	26.8 ± 3.6	1.80 ± 0.02	71.2 ± 2.3	Aerobic
B	(N = 9)	26.3 ± 3.7	1.78 ± 0.02	75.5 ± 3.4	Weight-bearing
C	(N = 9)	24.4 ± 2.8	1.78 ± 0.03	73.0 ± 2.5	Aerobic plus weight-bearing
Sedentary	(N = 18)	27.6 ± 2.1	1.78 ± 0.04	70.8 ± 3.4	None

*Mean ± standard deviation.

TABLE 2.—*Vertebral Measurements in Exercising Versus Sedentary Men*

Vertebral Measurements	*Study Group*		*Significance of Difference, P*
	Exercise	*Sedentary*	
	N = 28	N = 18	
Vertebral trabecular mineral, mg/cc	184.02 ± 18.7	161.34 ± 11.4	.0001
	N = 26	N = 11	
Vertebral integral mass, grams	41.61 ± 7.3	37.52 ± 4.3	.04
Vertebral size, cc	164.1 ± 29.8	148.6 ± 15.8	.18*
Vertebral integral density, mg/cc	258.28 ± 28.4	253.86 ± 29.3	.67*

*No significance.

aged 20 to 31 years (26 ± 3.3), the mean value for trabecular bone mineral density is 176.2 mg per cc (±21.4). Specific information, however, concerning level of current or past physical activity, diet and behavioral habits was not collected in the generation of these normal values. Thus, data from this group could not be incorporated into our study in which these indices were well defined. The value of 176.2 mg per cc is 9% greater than the control group mean (161.2 mg per cc) and the difference is statistically significant ($P = .004$). This value is about 4% lower than that for the exercise group (184.0 mg per cc), but did not reach statistical significance ($P = .15$). These comparisons confirm what might be expected: the mean value of trabecular bone mineral of a cross section of the population would fall somewhere intermediately between a sedentary group and a highly active group. Preliminary work on a cross-sectional basis has indicated that varying degrees of exercise intensity may be reflected in a corresponding increase in spinal bone density.[23] Further research over the entire spectrum of physical activity should serve to clarify whether any increase or decrease in physical activity will alter bone mass or whether an upper or lower threshold exists.

Results of cross-sectional population studies all show that there is a significant loss of bone with normal aging and that this occurs throughout the skeleton.[13,22,24,25] Bone mass usually increases to a peak in the decade between ages 30 and 40, then falls off gradually in both men and women, with an accelerated loss at the menopause in women due to the loss of estrogen production. An analysis of bone mass as a function of age in cross-sectional studies suggests that the rate of bone loss with aging is independent of the initial amount of bone[22,26,27]; therefore, persons who have more bone early in life probably also have more bone later in life. Longitudinal studies of rapid bone loss after menopause or oophorectomy support this finding by showing percentage rates of loss in the spine independent of initial absolute values.[15]

Persons in our sample engaging in a regular and rigorous program of exercise have more vertebral bone mineral than control subjects. With cross-sectional data such as these, however, it is unclear whether this increment will be continuous throughout life or whether the effects of exercise are transient, and whether the pattern of increase observed in our sample is the same in other race-sex groups. Furthermore, we cannot exclude the possibility that those persons with higher trabecular bone density are more likely to be physically active initially based on their increased skeletal size. A further evaluation of our questionnaire data may prove useful in interpreting these issues.

The design and implementation of various exercise programs as effective prophylaxes against bone loss and consequent fractures have not been well described or investigated. In vitro studies have indicated a relationship between bone strength and fracture[28-30]; a paucity of information exists that addresses these areas in vivo, however, especially in relation to the effects of various forms and degrees of physical activity. Therefore, we must design and develop new noninvasive methods of assessing bone strength and structure in exercising and nonexercising populations as a way of complementing our present knowledge of determining bone mass. A number of opportunities now challenge the clinical and research communities. Longitudinal studies will be necessary in diverse study groups to determine the long-term effects of exercise intervention.

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